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Integrated Design and Manufacturing for the Navy FBM Program

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Abstract:

The Integrated Design and Manufacturing (IDAM) project is bringing modern design, manufacturing, analysis, and test engineering methods to an established operational weapon system , the Submarine Launched Ballistic Missile (SLBM). The philosophy, methods, and constraints associated with technology application to enhance near term support and preserve long term engineering capability are presented.

Background

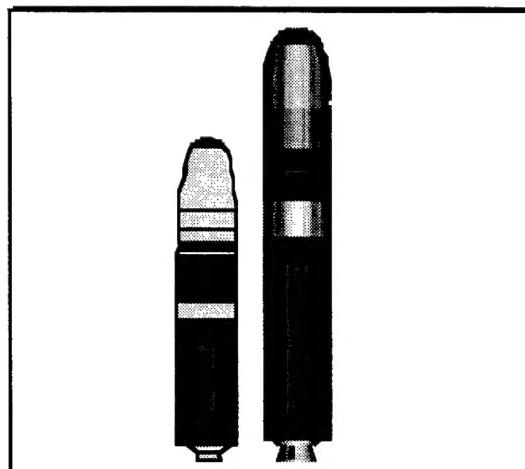
The current Fleet Ballistic Missile (FBM) C4 and D5 systems, shown in Figure 1, were developed with engineering software tools and methodologies over a 40 year period. These tools and methods were often specifically tuned (tailored) to a specific missile configuration and to the available ground and flight test data. Specific expertise and knowledge is required to employ these empirical tools and methods, particularly for hardware or environments that lie outside what was originally tested.

A decade has passed since the last FBM development program. The lack of opportunity to exercise core FBM design engineering competencies threatens skill and knowledge preservation in certain key areas. The problem of expertise retention is compounded by the fact that, in some cases, software and methods do not formally exist, have been lost, or reside as knowledge and experience of certain key FBM experts, most of whom have retired or are close to retirement.

Approach

The Integrated Design And Manufacturing (IDAM) Project has been sponsored by the Strategic Systems Programs (SSP) office of the U.S. Navy to apply modern engineering tools and methods to support the present FBM systems and preserve the capability to design and develop modified or new FBM systems if

needed. Figure 2 illustrates the key project elements.



	C4	D5
Length (ft.)	34	44
Diameter (in.)	74	83
Weight (lbs.)	73,000	130,00
Motor Cases	kevlar fiber ... graphite fiber	
Nozzles	1 ea. stage	1 ea. stage
Controls	movable flex-seal nozzles	
Range (nm.)	4,000+	4,000+

Figure 1. Fleet Ballistic Missile SLBM

Three major areas of activity are required to develop a strong foundation for cost effective, responsive engineering support of the FBM fleet: retention of the FBM design knowledge, establishment of a maintainable integrated analysis tool set, and use of computer modeling and simulation for rapid understanding of system behavior. That foundation enables workforce readiness and promotes process improvement. Current systems benefit from improved and accelerated fault isolation and correction capability. Integrated modeling techniques are available for the design and development of the replacement parts in event of age or environmentally-induced degradation. For any new FBM system, the development of three dimensional solid models of missile systems and their subsystems would support better and faster design, manufacture, test, and analysis of parts,

components, packages, and subsystems and in missile test analysis. Improved management and flow of data between analytical tools would increase engineering cycle efficiency. The IDAM Project successfully supports long term objectives of design engineering knowledge and skill preservation while meeting present needs to reduce FBM system life cycle costs.

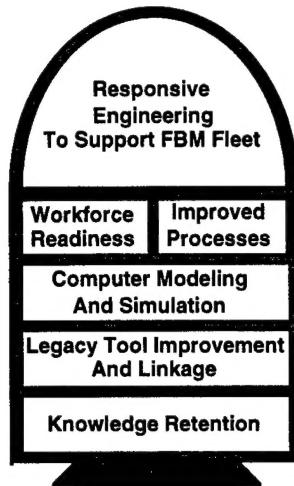


Figure 2. Key IDAM Project Elements

One major feature of any project attempting to improve the engineering process is to establish a process that has "buy in" of the people involved in performing the process. A small group of engineers seen as key performers in each of the technical organizations that support the FBM program make up the IDAM team. Each of these engineers identifies the areas of their organization that require further effort.

In the three foundation areas we are using a crawl, walk, run approach to inserting modern engineering technology into an established program.

In the crawl phase, the team identifies a need or improvement. The use of and implementation approach of the technology for engineering process improvement is researched. A simple prototype demonstration is then assembled. The team reviews the demonstration, determines the strengths and weaknesses of the proposed solution and sets objectives for later prototype versions.

The walk phase occurs when an opportunity presents itself. This could be a flight anomaly, a concept study, or support for a flight test. The approach developed in the crawl phase is applied to the problem in the best possible way. The improved engineering process is usually

conducted in parallel to the more standard approach, metrics on time to perform tasks and comments on ease of use are collected. The old and new methods are compared. If the new method shows a definite advantage then the item is then slated to become part of the normal way of conducting engineering analysis.

During the run phase a significant amount of effort is expended to develop a fully supported, user friendly, and sustainable process. Examples of effort performed in this step are developing an on-line documentation suite for a set of software tools (as part of our legacy tool improvement), documenting and training people in the appropriate use of detail in solid models (part of computer modeling).

The remainder of this paper will expand on the attributes of the foundation elements, followed by specific examples on how the engineering process improvements have shown a benefit to the FBM program.

The Foundation Elements



Knowledge Retention

Knowledge retention is a challenging objective of any program providing ongoing engineering support. The FBM is a high performance design operating in a non-benign environment. Providing engineering support of that design requires a combination of anecdotal, empirical, and physics based knowledge. That particular and often classified knowledge must be grown from within the FBM Program. Down sizing, personnel turnover, and retirement all deter knowledge retention.. However, to sustain a healthy current program and to preserve a viable future development capability, successful knowledge retention is essential.

Knowledge is "wisdom", integrated and synthesized, from various elements of information such as facts and rules for a specific domain. Explicitly, knowledge could be categorized by the following constituents in ascending order of representation quality and professional specialty for a given domain.

- o *Historical Information* - technical documents, reports, configuration data, test data and results

- o *Process Methods* - technical procedures, algorithms, models, software tools

- o *Heuristic Rules* - rules of thumb, lessons learned, reasons for success or failure
- o *Prediction Capabilities* - patterns, correlation, trending, regression

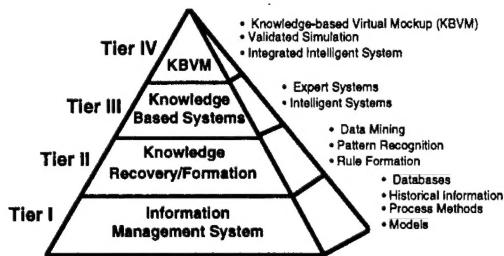


Figure 3. Knowledge Retention Architecture

A systematic approach to knowledge retention for IDAM has been adopted to reduce the information risk of relying on individual engineers or equipment and to fulfill information needs across the depth and breadth of the user base. The architecture supporting the implementation of this approach is shown in Figure 3. The bottom of the pyramid represents common entities for all workers to possess and the tip represents entities required for domain specialists.

Tier I: Information Management System

The information to be managed includes technical documents on models, algorithms, reports, procedures, design or analysis notes, data, and pointers to data files. The FBM Program manages that information using distributed, heterogeneous systems. Distribution is accomplished using World Wide Web search engines and utilities on an Intranet. Data warehousing techniques are being applied where the On-Line Transaction Processing (OLTP) systems can be integrated with a Decision Support System (DSS) for On-Line Analysis Processing (OLAP).

Currently the IDAM project works closely with the FBM/MDC (Missile Data Center) Data Systems Integration (DaSI) Project [Reference 1] to assure that the needs from designers and analysts would be satisfied to access the missile configuration and performance data. The DaSI data warehouse contains missile performance data such as those from missile functional tests, the Service Life Evaluation (SLE) tests, the trouble and failure reports, aging data, and a gateway to access the missile configuration records, the discrepancy reports, and the Flight Test Analysis Database (FTADB). The DaSI and FTADB projects are based on Oracle7 relational database

management system. The raw data from ground and flight tests will also be available to access. In addition, studies are being made in IDAM to identify the needs of centralizing the common data entities for designers and analysts to access, such as the materials property database.

Various documents containing historical FBM design and modeling information are being converted into the Portable Document Format (.pdf) linked with Webpages for online viewing. The techniques and standards developed for the Interactive Electronic Technical Manual (IETM) project is making are followed. Commercial tools are being explored to search the on-line information contained in Webpages as well as files in .pdf and image formats. The security issue for the Internet or Intranet has been a concern for any unauthorized disclosure. IDAM has developed a control procedure and a protection infrastructure to assure proper FBM information distribution over the network [Reference 2].

Tier II: Knowledge Recovery/Formulation

Information stored in database can be used directly to support design, analysis, and manufacturing activities. It also indirectly supports the formulation of new insights, understandings, and concepts. New knowledge lies within the data awaiting discovery. The systematic presentation of data would assist engineers in the discover and use of that knowledge, or data mining.

The IDAM project is looking at commercial off the shelf products for data mining. Software tools based on machine learning research are reviewed and applied to improve data mining results [Reference 3].

Neural network technology has proven viable in the areas of data classification and pattern recognition. The Lockheed Martin's Probabilistic Neural Networks (PNN) [Reference 4] and General Regression Neural Networks (GRNN) [Reference 5] work efficiently in mining temporal (time-series) data sets. Development of data mining techniques and methodologies have been planned for IDAM.

Tier III: Knowledge-based Systems

A Knowledge-Based System (KBS) represent technical domain knowledge by heuristic rules or models for information processing or inference. KBS applications cover design, analysis, manufacturing, monitoring, diagnosis, simulation, planning and scheduling. Although

pure rule-based systems have limitations on robustness and inclusiveness for all possible situations, they are effective in advising and training new designers and analysts. KBS applications have been planned for IDAM to support design, analysis, manufacturing, and product cost analysis.

Tier IV: Knowledge-based Virtual Mockup

The Knowledge-Based Virtual Mockup (KBVM) provides a virtual missile capable of undergoing a physics-based virtual flight using validated models and simulations. Design engineers and analysts will be able to evaluate and diagnose the performance with the built-in knowledge and with solid model geometry in a virtual reality environment. Although ambitious, it is conceivable that this may be reached after the lower tiers of the knowledge retention pyramid of Figure 3 are accomplished. Achieving a KBVM capability is a long-range goal for IDAM.



Legacy Tool Modernization And Linkage

FBM legacy engineering software is that software used for the development and operational support of FBM within the Flight Sciences community. Flight Sciences includes Aerodynamics, Flight Dynamics and Simulation, Gas Dynamics, Guidance and Control, Hydrodynamics, Loads and Dynamics, Mass Properties, Propulsion, Structural Analysis, Thermodynamics, and Vulnerability and Survivability. Software is considered to be legacy software if it has history of validated use behind it. FBM legacy methodology and software, developed over a 40 year period, represents the only validated means for analytically verifying the FBM design. Preservation, especially of little used legacy software, is important to ensure that if the need arises to address potential fleet issues, the necessary analytic tools will be ready and in place.

A six step approach, shown in Figure 4, is used to preserve and modernize FBM legacy software.

1) Apply software standards and establish configuration control and software baseline libraries (software repositories containing source code, executables, documentation, and test cases). FBM legacy software is engineering development software which has not, up until now, been rigorously controlled or documented. The IDAM software development process is based on Lockheed Martin procedures and the

IEEE-1498 Standards [Reference 5], but modified for the non-deliverable legacy code.

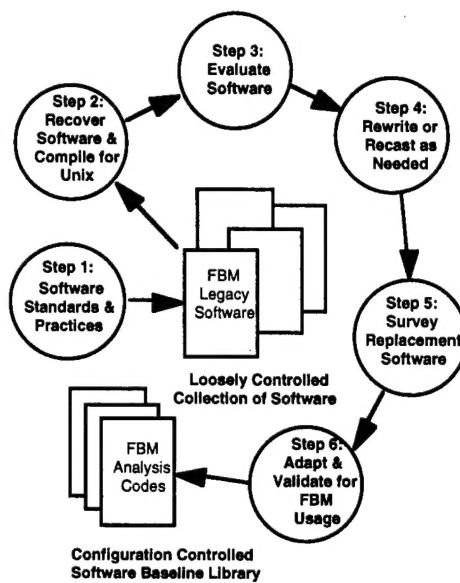


Figure 4. Legacy Software Preservation and Modernization Approach

Software standards are an important step towards establishing a more rigorous process of engineering software creation and control. IDAM has elected to use a phase-in approach in which software standards are tailored towards legacy software modernization and maintenance. There is a balance that must be reached between scope of the software standard implementation and the cost benefit of applying such a standard to existing legacy code.

The IDAM approach is to use common sense practices on short duration projects (one man month or less). This puts in the hands of the developer the decision as to what type of standards to use. For new software development of appreciable length (six months or more), a more rigorous approach is used where requirements and architecture design are defined documented and peer reviewed (a formal review requiring reviewers to take on different roles) before coding commences. For software projects that lie in between these two extremes (usually, this means legacy code rewriting), the level of standards to be applied are decided on a case by case basis. Eventually, all software may follow the same exacting standards, but until more experience is gained in the process, this gradual "crawl-walk-run" approach will continue to be used.

Considerable work has gone into defining and prototyping software baseline libraries. Software

baseline libraries contain both the archive for the source code and the location of operational executables. Ideally, they also contain all documentation, test cases, and validation results. Realistically, they include as a minimum the baseline source code and executable for each analysis tool. The IDAM approach is to use a distributed series of software baseline libraries, where each analysis discipline maintains their own codes.

- 2) Resurrect old analysis tools in unique discipline areas. Tools are rehosted on the current UNIX computer platforms. Documentation (user's guides, verification and validation data, source code listings, theory guides, etc.) is collected or recreated. Test cases are rerun.

The difficulty of this task varies. In some cases, the code recompiles correctly the first time. In others, input and output problems and non standard command sets (like VAX FORTRAN extensions) cause considerable modification before a code will execute. Often documentation is fragmented or nonexistent.

- 3) Evaluate and understand the analysis tool limitations. Educate the current FBM engineering community in the limits of the tool's domain, its shortfalls, and potential maintenance problems. This "refamiliarization step" often involves an engineer who is unfamiliar with the analysis tool.

4) Rewrite, recast, or otherwise modernize the code into modern accepted languages with current architectures. A typical example is rewriting a FORTRAN IV based code full of goto statements into structured FORTRAN 77. Sometimes a new language is selected altogether (for instance, from FORTRAN to C). In selected cases, graphical user interfaces are implemented to refresh an older command driven tool.

- 5) Survey and assess current and emerging analysis techniques, methods, and computational approaches for potential replacement or technology insertion. Since it has been ten years since the last development program, new software and hardware technologies are now available for use in supporting FBM. A typical example is the use of computational fluid mechanics to predict premature aerospike flow reattachment. A major goal of this step is to replace current empirical methods (based on ground and flight tests) with a more predictive approach.

6) Develop or adapt technology for use on FBM and validate it. Modern commercial or freeware can be used for engineering analysis. Unique FBM environments and legacy software interfaces may necessitate modification of these tools prior to adaptation of new technologies. Validation of all new or modified tools using old test cases, flight data, and ground test data is an important final step towards making this software operational.

Discipline Encapsulation

In addition to legacy software modernization, the IDAM project is improving the ways in which this software is being used. To reduce engineering analysis costs the tools and methods for data gathering, data translation, data processing, input file setup, and post processing are being updated and streamlined, and the concept of discipline encapsulation is being pursued. Figure 5 shows the IDAM discipline node model in which each engineering analysis discipline is conceptually encapsulated in a bubble node. Within each node are all the FBM legacy software codes, utilities, workflow tools, and databases that are "owned" by the applicable discipline. At the heart of the node is the discipline expert who ensures proper usage of the tools and validates the results. Discipline encapsulation reduces data formatting time, allowing more time for data analysis and interpretation.

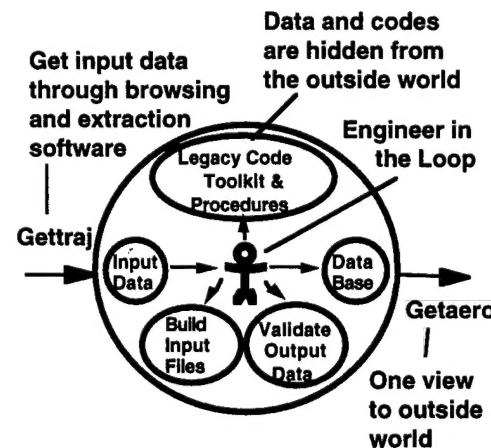


Figure 5. Discipline Node Model

Data transfer between disciplines is handled by standardized, well defined general browsing and extraction interfaces that minimize code-to-code translation.

A recent success of the IDAM team is the establishment of Common Standard for

representing physical units of measure in such a manner as to be easily parsable (readable) by both a computer and human beings. This included descriptions of unit symbols (i.e., in = inch, m = meter, s = second), units formulas (i.e., in*lb/s^2), referenced conversion factors, and unit conversion software, both UNIX and world wide web based.

The pursuit of a common browsing and extraction standard allowed common tools to be placed on top of the data browsers. Tcl/tk programming [Reference 7] was used to prototype this technique to bring a common graphical user interface and physical unit conversion to any getxx compatible browsing program.

The encapsulation approach allows discipline nodes to be viewed as plug and play elements in a larger simulation. The simulation model is not tightly coupled and is distributed in nature. Each discipline is given the maximum flexibility to select the right software tool for the job. The inherent scalability enables new tools to be added without drastic modification to other parts of the system.

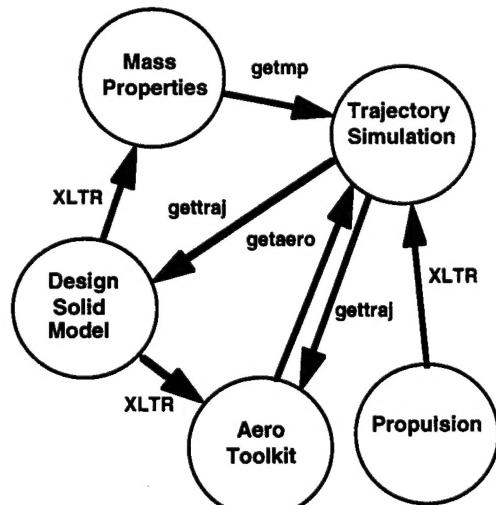


Figure 6. Prototype Node Model

A prototype implementation of the node model is in development (see Figure 6). It consists of a standard command driven interface and output format, and three operational prototypes: getaero, for extracting aerodynamic coefficients, getmp, for extracting mass properties, and getraj, for extracting flight trajectory data. There are also the more traditional code-to-code translators making the prototype a hybrid.



Computer Modeling And Simulation

Solid modeling and simulation are ideally suited to system level engineering. The solid model in concert with animation software and an accurate physics based flight dynamics code enable engineers to simulate flight. Launch through reentry may be simulated to assess missile performance. Solid models and simulations may be used to resolve systems and system performance into more detailed structures and electrical/electronic subsystems and subsystem performance. Solid models can provide a common design feature database for multiple disciplines. The functionality of these features may then be verified, prior to supplier selection and purchase.

Relative differences in the nature of structural and electrical/electronic products influence the practical application of the models. Solid model structural configuration items, while coupled, may be developed in parallel and then assembled. Solid model electronic and electrical configuration items are best developed using a top-down methodology. Although solid modeling and simulation span the breadth and depth of the product life cycle, the IDAM Project has found that the tools and techniques may be inserted piecemeal into the organization to accommodate the priority funding levels of the organization.

Electronic communication management tools can significantly enhance the availability of model and simulation data to program personnel. Intranet web and product data management and workflow technology provide a spectrum of distribution pathways. The IDAM Project is linking engineering knowledge to Computer Aided Design (CAD) tools using an internal web. Product Data Management (PDM) tools are being much more slowly phased in. Currently, key documents are being placed in PDM repositories to support new projects. Large scale PDM implementation has high costs that are likely not easily recoverable on a mature program like FBM.

Solid modeling of structures is used on the FBM Program to create detailed part models, detailed drawings, support model based manufacturing techniques, cable and wire harness design, and assembly models. Assembly models in turn provide assembly drawings and support computer based analysis and simulation.

Effective employment of solid modeling in a production environment requires that an organization understand and address solid model fidelity, and verification, configuration management.

Solid model fidelities have been quantified and defined at percent fidelity levels as shown in Figure 7 to aid in ensuring that appropriate and affordable engineering support tasking and levels meet customer expectations and needs shown in Figure 8. Current limits in computer CPU, RAM, memory, and graphic processor as well as application and network bandwidth capabilities require the solid model task be fitted to available technical resources and customer funding.

Fidelity	Level	Progressive Fidelity Reduction
100%	Assy	All parts.
	Parts	All features.
95%	Assy	Above except fasteners and connectors have similar, simpler geometric shapes.
	Parts	Above except surface feature detail limited to mating surfaces.
85%	Assy	Above except fasteners and connectors included only where critical to model.
	Parts	Above except no features like fillets or chamfers on any part.
70%	Assy	Above except only primary structure, envelopes, and major cable runs with connectors and assemblies.
	Parts	Above except minor features missing.
50%	Assy	Above except only primary structure and envelope. Simple geometries. No fasteners, connectors, cables, hydraulic lines, etc.
	Parts	Above except major features missing.

Figure 7. Solid Model Fidelity Definition

Model Use	50%	70%	85%	95%	100%
Conceptual Study	X				
Initial Mockup		X			
Detailed Mockup				X	
Preliminary Analysis		X			
Detailed Analysis			X		
NC Manufacturing				X	
Simulation	X				
Detailed Drawings			X		
Assembly Drawings				X	
Special Drawings and Mockups					X

Figure 8. Minimum Fidelity Requirements

The official design configuration of the FBM is controlled by diamond stamped drawings. Before solid models can replace the drawings as the official configuration, the solid model must be verified. FBM engineers use a buddy check method at this time. All solid model dimensions are checked against the diamond stamped drawing's dimensions by a second engineer. If a correction is needed, it is made and a third engineer checks the solid model. This process proceeds until an independent check of the model verifies 100% dimensional compliance with the diamond stamped drawing.

The usefulness of solid models places new demands on configuration management. Different model file formats of the solid model are needed by different disciplines and for different purposes within the integrated product development environment. These formats must be logically and functionally linked to the correct native format model file version.

The SDRC Team Data Manager repository is used to store 2D and 3D native model files as well as the data relationships between assemblies. Libraries are created within the repository to support projects. Engineers model their conceptual designs into initial state model files. As the design progresses it is promoted to a preliminary and then finally a released state. Product data management technology is used to distribute the file format useful and usable by project participants. Selected 2D raster images are passed to the release group for configuration control drawings. File names and electronic locks are used to link the multiple formats back to the native file format and ensure data integrity. Currently, only the solid design engineer is able to assure that data relationships between different assembly levels are maintained and are useable.

Solid modeling and simulation are applied to support the design of electronic and electrical subsystems. A need exists for the electronic and electrical models and simulations to support the current operational C4 and D5 FBM fleets as well as be responsive to any new design and development needs. The goal is to ensure continuity of electronic and electrical performance through a potential continuum of piece part replacement through subsystem upgrade to new system design. In all cases, the intent is to model and simulate as much as possible prior to first build to reduce the number of prototype iterations to one prior to production.

The top down approach is shown in Figure 9. System level simulation tools evaluate the system performance of the design concept. System text and mathematical descriptions are allocated to electrical/electronic configuration units and developed into behavioral Very High Speed Integrated Circuit Hardware Description Language (VHDL) descriptions. Simulations assess the design's functional performance of the system requirements allocated to the electrical/electronic configuration units. The behavioral descriptions are constrained and developed further into a synthesizable VHDL-Register Transfer Level (RTL) description. The synthesizable description function is evaluated by simulation and developed further into a technology based structural VHDL description using logic synthesis tools. The structural VHDL description provides board level models and schematics for piece part evaluation, simulation, production.

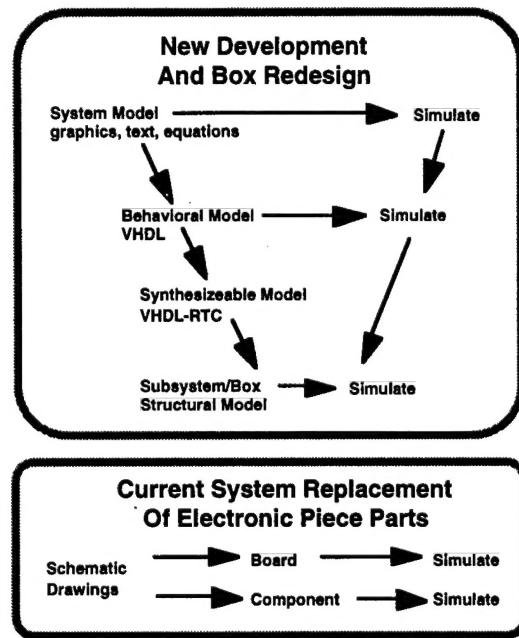


Figure 9. Top Down Approach

Responsive Fleet Support



Workforce Readiness/Improved Processes

The tools, methods, and technologies established by knowledge retention, legacy tool modernization and linkage, and computer modeling and simulation has laid a solid integrated foundation for FBM engineering support. The people and processes behind FBM engineering have benefited in the areas of design, analysis, manufacturing, and test.

Mechanical Design

Computer Aided Design (CAD) tools and solid modeling not only benefit new missile design but also operational missile support. Structural, electronic, and electrical solid models have been linked to route cable harnesses in the missile. Solid modeling and analysis tools show promise for the area of cable and wire harness design. The FBM program is currently pursuing a project to evaluate tool combinations to reliably perform this function. The logical connectivity of pins is captured in MentorGraphic's L-cable. The physical design of electronic packages, missile free volumes, connectors, receptacles, and cable clamps is created in SDRC/IDEAS. IDEAS's Harness Design tool accesses this information and then designs and displays the configuration of a feasible wire harness. The designer may then "pull" and "clamp" the wire harness around and onto the missile structure. The capability of this toolset to design a wireharness was proven in a simple preliminary test. Use of this tool would prevent finding out too late that a needed cable was too short. The wire harness design accounts for bend radii but must be interactively adjusted for operationally required slack.

Solid models are used to sustain the operating fleet. A redesign of a C4 avionics box had been proposed. We desired to know if the box could be also used on the D5. Conventional logic indicated that since there was more room on the larger D5 there would be no problem. Use of a solid model enabled the engineer to evaluate physical interference with other packages as well as thermal interference with Post Boost Control System (PBCS). The PBCS thruster plume was modeled as a function of heat rate. Viewing the plume and the proposed box design immediately indicated that a heat rate in excess of box cable insulation ratings would impinge upon several cables. Solid model evaluation of interference required 4 hours instead of 8 using conventional methods.

Electronics Design

Simulation with electrical/electronic models preserves D5 missile capability. Since the D5 missile was developed prior to the availability of today's tools, many electrical/electronic models are being developed from schematics. Naval Surface Weapon Center (NWC) Crane is modeling piece parts and simulating their logical operation. Then LMMS is building board models and linking MentorGraphic and IDEAS CAD tools to perform board level vibration, shock, and thermal stress testing by simulation.

If piece parts used in the original D5 design need replacement but are not in current production, board level simulation of replacement candidates will assure that the new part maintains missile performance at present levels. Test capabilities in the Mentor Graphics tool suite that analyze the solid model greatly reduce test costs and test times.

Analysis

The aerodynamics discipline is one of the IDAM pathfinders for discipline encapsulation. Before IDAM, aerodynamics consisted of a dozen or so uncoupled codes for defining base drag, aerodynamic coefficients, and aerospike performance. Data processing was extensive in that the outputs of several computer codes had to be combined together by hand in order to generate an aerodynamic model in part, because of the lack of a generalized database storage format. Data transfer consisted of formatted file transfers as required by the code receiving the data, formalized memos, and informal correspondence. The aerodynamics legacy codes were for the most part, collocated, although some computer codes were not running on the current UNIX platforms, and documentation was scarce or did not exist.

Under IDAM, an aerodynamics software baseline library is being implemented, a consistent user interface prototype called runaero was created to reduce setup time for several of the most widely used software (this will be expanded to eventually contain all codes in the aerodynamics toolkit), a utility for data combining and massaging called modaero is being written to streamline the process for creating an aerodynamic coefficient tables (i.e., the aerodynamic model), a common database storage has been defined and implemented, and a standardized way of browsing and extracting the data (getaero) has been written. The end result is a streamlined process which will require less hands on data processing and reduce overall analysis time. In all cases, the rewrite process gives engineers renewed incite into the FBM system. Test case generation, methodology review, documentation, and education are all benefits seen in IDAM.

Manufacturing

The FBM Program has investigated emerging technology to reduce the cost of design and manufacturing of, as well as, improve the producibility of current missile composite parts. Computer-based three dimensional composite part models provide the means to dramatically

improve composite part design and fabrication. The composite part external envelope (and tool surface) is designed in IDEAS. The most dimensionally controlled or controlling surface is identified as the tools surface. Ply boundaries, warp direction, and materials are defined in the model. Part functional performance is analytically evaluated with finite element analysis. An IGES file of the tool surface and ply boundaries is passed to a computer ply unwrapping software tool. Ply sequence of placement on the tool surface, material thickness, lay-up, fiber orientation, are designated. A triangular mesh model of the plies is created. The ply is progressively "flattened" by the computer into the two dimensional ply pattern to be cut from the roll of composite material. Strain in the mesh elements are then converted to tensile or compressive stress on the material. The engineer may view the stress and alter the ply shape or create darts (diagonal edge cuts outs) to prevent material stretch or puckering. Each 2D ply may then be electronically passed to a nesting program that most efficiently arranges ply kit patterns to be cut from lengths of material by a CNC ultrasonic knife. Kitting and lay-up of cut plies in the correct order is aided by an overhead laser projector. The laser projector, based on unwrapping software solid model information, eliminates the need for costly mechanical tooling used for ply placement. This linkage of tools creates a true closed-loop design system.

Test

Test planning and analysis has benefited from the activities of the IDAM Project. Solid modeling, simulation, dynamic, and visualization codes provide Test with improved pre-flight and post-flight analysis capabilities.

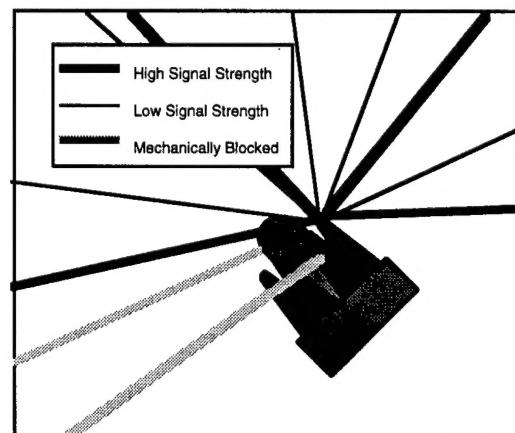


Figure 10. GPS Preflight Simulation

In support of pre-flight planning and analysis, the interaction of a proposed FBM missile flight test trajectory with optical and RF ground stations may be evaluated to define the optimal tasking of range support units. Similarly, the quality of uplinks to GPS satellites for a proposed antenna design were simulated prior to launch. The simulation resulted in a recommended launch window within the larger available launch window that minimized acquisition time and maximized the quality of the spatial arrangement of orbiting satellites. Figure 10 illustrates the modeled links between missile and satellite constellation.

Post-flight test analysis performs the essential task of validating the missile system performance by examining test data collected. Flight test data is used to validate the simulation models. In addition, flight test data is used for fault detection, diagnosis, and isolation. In an actual flight, a flight anomaly was evaluated using side-by-side animation of the planned trajectory and actual telemetry. The cause of the behavior was postulated to be on the equipment section of the missile. The solid model of the equipment section was assembled in various equipment configurations and manipulated on screen to provide engineers with perspective for diagnosis not available from any physical mock-up (see Figure 11). This information along with other diagnostic efforts isolated the suspect fault to a specific location of the Post Boost Control System.

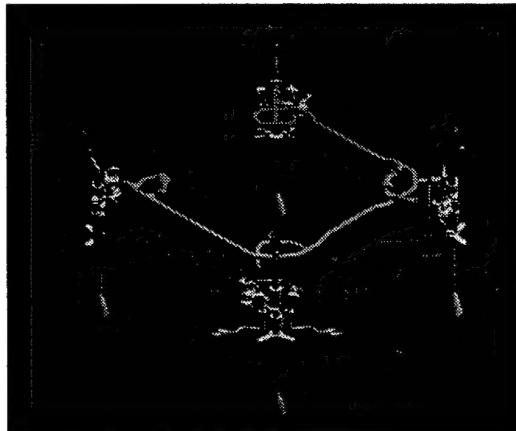


Figure 11. PBCS Solid Model View

Conclusion:

The IDAM project has developed a process and approach for inserting modern engineering information technology into the FBM Program. Utilizing these new tools we have demonstrated a measurable improvement in speed when responding to fleet questions, and we have made FBM design information and lessons learned

available to a future generation of FBM engineers.

The processes developed to improve the retention of legacy software tools has become part of the way business is done, and the FBM program is already reaping the benefits of improved understanding of FBM unique tools and retention of skills. The FBM unique analysis tools have been restored, and are in the process of documentation for future engineers.

An additional benefit of the IDAM project is improving the cohesiveness of the engineering organization. This type of tight interaction usually occurs only during a full scale engineering development programs. We have established stronger bonds between the Design, Analysis, Manufacturing , and Test organizations. This has improved our capability to perform problem resolution. The members of the team are actively working with other information technology tasks within the FBM program, the Department of Defense, and the Lockheed Martin Corporation. Utilizing the experience of these groups greatly enhances our ability to improve the FBM engineering process.

The IDAM project successfully demonstrates that modernization of the engineering process can be judiciously added to an ongoing mature weapon system program.

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Integrated Design and Manufacturing for the Navy FBM Program

*Phillip H. Robidoux, James R. Stubbe,
Stephen H. Rousseau, and Rex C. Tsou*

Lockheed Martin Missiles and Space

Improved Engineering Methods for the Navy FBM

*Bringing modern design, manufacturing,
analysis and test methods to the
FBM program*

- Solid models

- Software development and *design process improvement*

- Information capture and *knowledge retention*

Enhancing fleet support



Background

Mature weapon system program with 40 year history

Development gap

Long term support required

Established process to instill new development approach into program

- *Crawl, Walk, Run*

Started in January 1994, planned funding through October 1997

Philosophy and Approach

Cross functional teams

*Inclusion (including other efforts
industry and defense contractors)*

Long term vision, short term plans

Plan, do, check, act

Crawl, walk, run

Spiral development

Do the right thing

Key IDAM Project Elements

*Knowledge retention
Legacy tool
improvement and
linkage*

*Computer modeling
and simulation*

**Responsive
Engineering
To Support FBM Fleet**

**Workforce
Readiness**

**Improved
Processes**

**Computer Modeling
And Simulation**

**Legacy Tool Improvement
And Linkage**

Knowledge Retention

Knowledge Retention

Web based document display
Document context search utilized

- o Knowledge-Based Virtual Mockup (KBVM)
- o Validated Simulation
- o Integrated Intelligent System

Tier IV KBVM

- o Expert Systems
 - Rule/Model/Case-based
- o Intelligent Systems

Tier III Knowledge-Based Systems (KBS)

Tier II Knowledge Recovery/Formation (KRF)

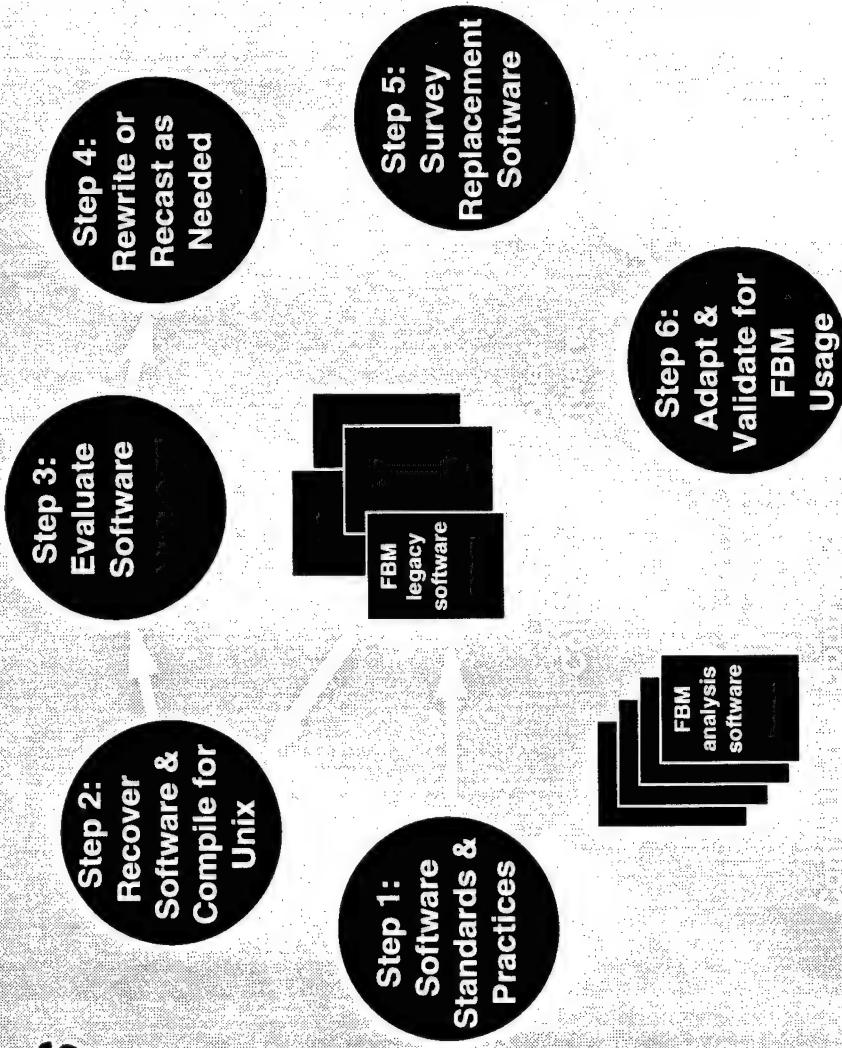
- o Data Mining
- o Pattern Recognition
- o Rules Formation

- o Databases
- o Historical Info
- o Process Methods
- o Models

Tier I Information Management System (IMS)

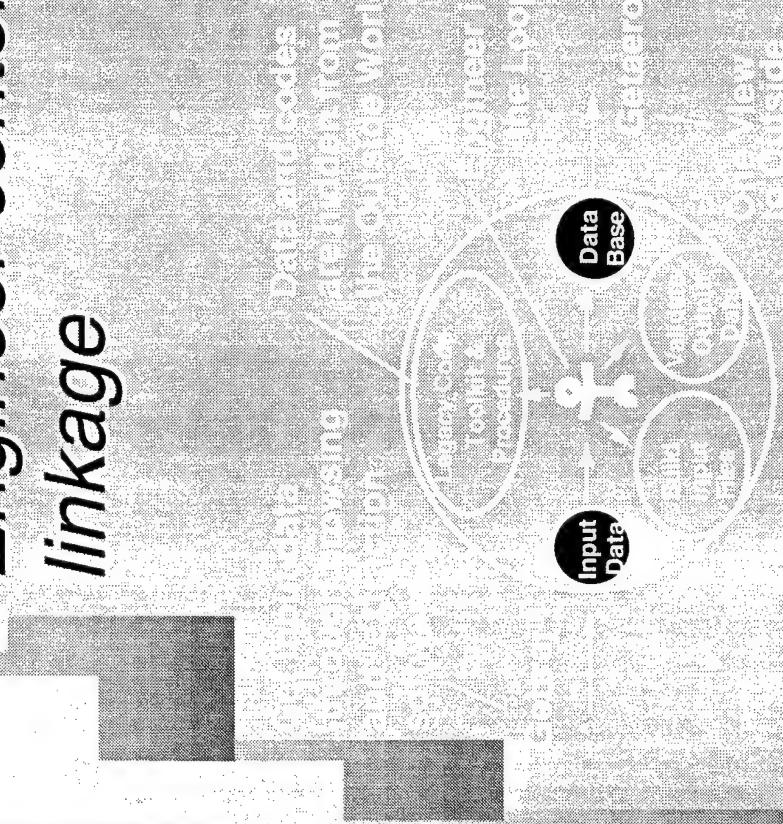
Legacy Tool Modernization

*Unique FBM
analysis tools
retained
Systematic
preservation
approach
followed*



Legacy Code Tool Kits

Engineer centered approach to tool linkage



Computer Modeling and Simulation

Workable process established Progressive model fidelity defined

100%	Assy Parts	All parts. All features.	Above except fasteners and connectors have similar, simpler geometric shapes. Above except surface feature detail limited to mating surfaces.
95%	Assy Parts	Above except fasteners and connectors included only where critical to model. Above except no features like fillets or chamfers on any part.	
85%	Assy Parts	Above except only primary structure, envelopes, and major cable runs with connectors and assemblies.	
70%	Assy Parts	Above except minor features missing.	
50%	Assy Parts	Above except only primary structure and envelope. Simple geometry. No fasteners, connectors, cables, hydraulic lines, etc. Above except major features missing.	

Computer Modeling and Simulation

Minimum fidelity requirements

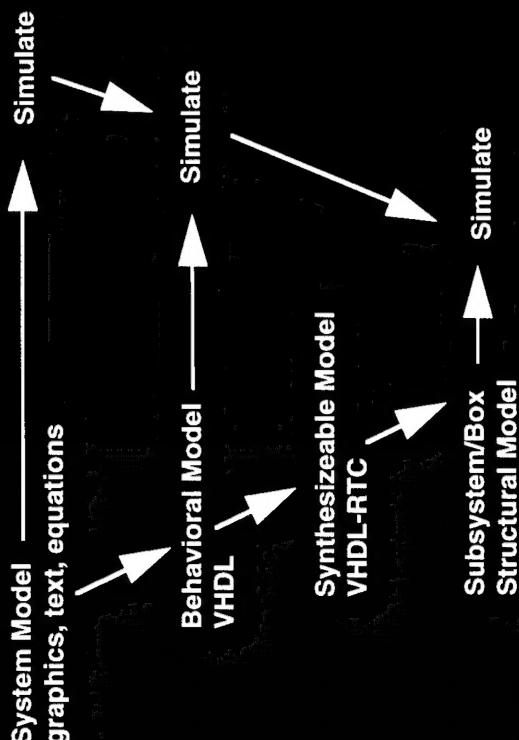
	50%	70%	85%	95%	100%
Model Use					
Conceptual Study	X				
Initial Mockup		X			
Detailed Mockup			X	X	X
Preliminary Analysis			X		
Detailed Analysis				X	
NC Manufacturing				X	
Simulation			X		
Detailed Drawings				X	
Assembly Drawings					X
Special Drawings					
and Mockups					X

Electronics Modeling and Simulation

*Top down
approach
established*

*Electronics
models and
simulation in
development for
D5 missile*

New Development And Box Redesign



Current System Replacement Of Electronic Piece Parts



Conclusion

- Technology insertion process and approach established*
- Legacy software tools being retained*
- Successfully demonstrated mature weapon system program can use modern engineering tools*
- Improved capability to support the fleet*

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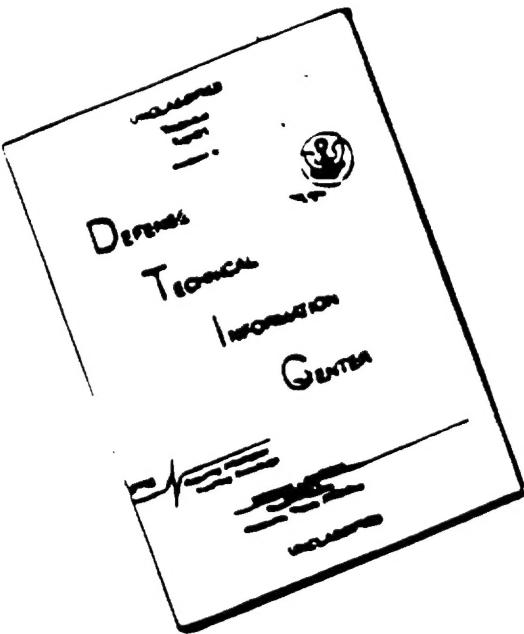
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